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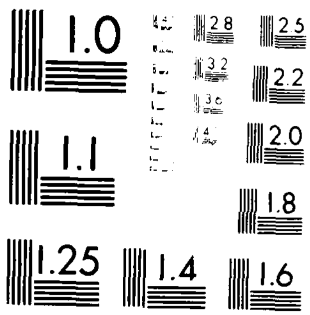

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FUNCTIONAL REQUIREMENTS FOR
A COMPUTER GRAPHICS MODEL OF
A MAINTENANCE TECHNICIAN

Dennis F. Spray, Captain, USAF

LSSR 63-83

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Recent emphasis by the Department of Defense on maintainability and supportability in weapon system design dictates developing a computerized, bio-mechanical maintenance technician model that interfaces with computer aided design (CAD) systems used by the aerospace industry. In order to determine the functional requirements of this model, 15 maintenance officers and 15 human factors engineers were consulted using a structured, purposive interview schedule with sampling based on availability and convenience. Using the statistical modes and means of the responses, the general maintenance tasks, the body positions for these tasks, and the human factors assessment diagnostics required for simulating a line maintenance technician were prioritized. Also, the study determined what operational clothing requirements are necessary for simulation.

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FUNCTIONAL REQUIREMENTS FOR A COMPUTER GRAPHICS MODEL OF A MAINTENANCE TECHNICIAN

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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September 1983

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CHAPTER 1

INTRODUCTION

> We want equipment which requires the least number of operators and which is easiest to support. We must avoid hardware so sophisticated that it cannot be properly maintained by our users. Whenever possible, we would like to see more reliance on commercial off-the-shelf components and equipment. In short, industry must contribute by designing the best, least complicated operating and support features into the equipment delivered to the DOD [6:3].
>
> Frank C. Carlucci, Deputy
> Secretary of Defense

Maintainability and supportability are facets of weapon systems acquisition that are historically considered only after the system enters the demonstration, test, and evaluation phase of the acquisition process. This strategy inevitably leads to multiple design changes and increased procurement costs. Richard D. DeLauer, Under Secretary of Defense, Research and Engineering, related this problem to the 98th Congress:

> In much the same way that we have experienced cost problems in the acquisition of our weapons, we have had substantial growth in the cost to support our weapons and in the technical competence required to maintain them. The objective of developing weapons which will be less costly to support often requires additional schedule time and funds during a period when we are seeking to field new systems with shorter R&D time and at reduced acquisition costs [18:III-8].

According to Dr. William B. Askren, Air Force Human Resources Laboratory (AFHRL), three trends prevail that offer opportunities for incorporating supportability and maintainability into the design process early and aid in remedying soaring acquisition costs (1:221). First, in order to streamline and improve the Department of Defense (DOD) acquisition process and to rein in on escalating acquisition costs, Mr. Carlucci (9:13) issued 32 management initiatives in a memorandum dated April 30, 1981. Of particular importance to the maintenance and logistics support area, Recommendation 16 (9:19) stated:

> There is a need for industry to apply more of their design talents to reducing reliability and support problems. Beyond this is a need to improve the identification and specification of maintenance manpower constraints and for industry to include the constraints in the design.

This guidance mandated both contractors and DOD procurement personnel to consider human factors along with cost, schedule, and performance parameters in the early stages of acquisition.

Secondly, the AFHRL (1:221) conducted feasibility studies for incorporating "maintenance and logistics support characteristics" into the early, conceptual phase of acquisition. The results of the studies indicated a high probability for adding maintainability and supportability to the design stage and:

. . . one of the best ways to improve design for support is to put the maintenance and logistics data and factors directly into the daily working procedures used by the design engineering personnel [1:221].

Finally, the extensive use of computer aided design (CAD) within the aerospace industry would facilitate interfacing maintainability and supportability into the design process. Primarily, two advantages of CAD are responsible for allowing this interface. First, CAD provides rapid performance analysis and human decision making in design-cost tradeoffs. Second, use of three dimensional (3d), high resolution (hi-res) graphics permits speedy interaction with manufacturing and design data bases for on-the-spot corrections and changes while significantly decreasing the time and requirement for drafting the design.

Kenneth L. Clark (8:43), manager, Computer-Aided Design Service, Integrated Logistics Support Division, Westinghouse Electric Corporation, foresees significant cost savings for the producer and customer by including integrated logistics support early in the acquisition process. By the very nature of military procurements, the end product is highly customized and requires excessive labor to manufacture. Thus, through integrating logistics support and maintenance factors with CAD, both contractor and customer realize the benefits of lower costs along with a highly supportable and maintainable weapon system.

Building in maintenance and logistics support decisions into the acquisition process dictates an interface between the human factors engineer, the maintainability engineer, and the design engineer. This interface historically occurs during completion of the demonstration, test, and evaluation phase of the acquisition process. At this point in time, the full scale engineering and development phase, any changes in the design for supportability and maintainability require major weapon system redesign efforts and commensurate financing. Under this handicap, cost considerations usually suboptimize supportable and maintainable designs.

However, computerized human models exist that allow the design engineer and human factors engineer to analyze cockpit configurations in the conceptual phase. These models permit assessing work station layouts subject to aircrew member physical constraints. The assessments consist of determining whether the aircrew member can reach a particular control item with his hands or feet while in a sitting position. The constraints involve the aircrew member's physical dimensions, whether he is wearing a seatbelt and shoulder harness, and whether the harness is locked or not. Also, most of the models include the ability to assess visual scanning under the same constraints.

Although these models are excellent tools for the human factors interface with design engineering, they limit themselves to a specific function--namely, cockpit configuration design. Therefore, the design engineer who relies heavily on his CAD system is unable to assess the maintainability and supportability feasibility of his conceived weapon system from a maintenance technician's viewpoint. In turn, this proliferates the nominal attention to the human factor interface.

Problem Statement

In order to improve the ability to assess the maintainability and supportability characteristics of the system in the design phase of the acquisition process, a computer-based, bio-mechanical, maintenance technician model needs to be developed for interface with existing CAD software. This interface should allow the design engineer to ensure the weapon system and its subsystems are maintainable and supportable from a maintenance technician's perspective. This affords adjustable designs prior to formalization and avoids expensive engineering changes later in the acquisition process.

Scope

There are two main constraints that limit the scope of this research. First, the effort will focus on the line

maintenance technician. This is the person, whether in organizational (OMS), field (FMS), avionics (AMS), or munition (MMS) maintenance squadrons, that physically works on the weapon system on the flight line or in the silo. Second, the research will consider only the generic maintenance tasks performed by the technician, along with the body position(s) for accomplishing these tasks, and the human factors assessment diagnostics for assessing the maintainability and supportability characteristics of the weapon system design. This second constraint is based on the work of Herbert M. Reynolds described in "A Foundation for Systems Anthropometry." Reynolds (16:6) presents "a systems overview of how the major parameters in a simulation would be utilized relative to the type of parameters and type of data." Figure 1 illustrates his corresponding logic diagram (16:5). According to Reynolds, the simulation requires determining the task and body position first. Then, the more detailed environmental parameters and the probabilistic body dimensions are defined for the "man-machine" interface. Lastly, the "compliance evaluation" or human factors assessment diagnostics are established for the simulation. Thus, this research effort focuses on the initial parameters for definition (maintenance tasks and the body positions for these tasks) and the output "compliance evaluations" (human factors assessment diagnostics).

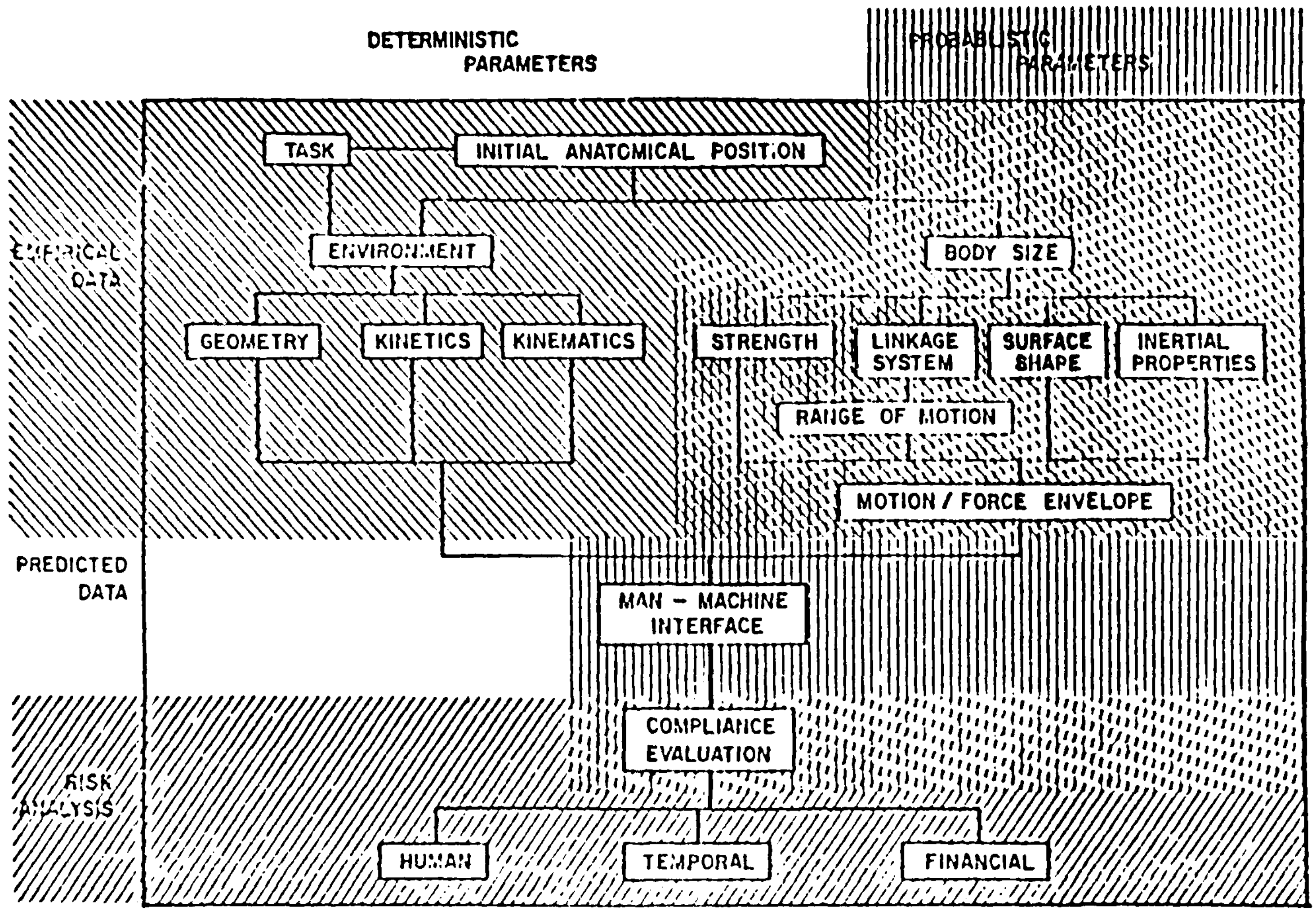

Figure 1. Systems Analysis of "a Priori" Design Approach Utilizing Systems Anthropometry.

Research Objective

The objective of this research is to determine the functional simulation criteria for a computer-based, biomechanical maintenance technician model which can be used to evaluate proposed equipment designs, and which interfaces with existing CAD systems used in the aerospace industry.

Limitations

The following constraints further limit this research effort:

1. This effort develops specifications for the model. It does not formulate the computer model.

2. The specifications focus primarily on line maintenance technicians, as opposed to base level (shop) or depot level maintenance.

3. General maintenance tasks will be standardized into generic categories. Examples are servicing, repair, replace, etc.

4. It does not consider human response times nor normal times for task completion. Furthermore, the model will not be employed to develop standard and normal times for task completion.

Research Questions

This research addresses the following questions:

1. What general maintenance tasks should the model simulate for maintainability and supportability considerations?

2. What body positions are relevant to the performance of these maintenance tasks?

3. What human factors assessment diagnostics are required in the model in order to optimize the human factors/maintainability interface with the weapon system design? Examples include ability of the technician to fit his body or limb into the space provided for task completion and the technician's ability to see the component or subsystem in the area he is working.

4. What operational clothing requirements are relevant to the model simulation?

CHAPTER 2

REVIEW OF LITERATURE

Overview

This chapter presents a discussion of several human body simulations developed by differing sectors of society. First, it summarizes the models developed by industry for human factors considerations in product design. Next, it presents models formulated in the academic community. Then, it reviews military simulations employed for ergonomically designing crew compartments of weapon systems.

Industrial Models

Primarily, industry led the way in developing computerized human models and applying them for human factor considerations in work place design. The Boeing Corporation developed one of the first models, appropriately named Boeman (10:22). Boeman presents a 23-joint, human model in 3d, vector graphics for aircrew member work station design. It allows analysis of reach, interference, avoidance, and collision during task completion, along with visual interference analysis. Also, the operator may assess task completion under seatbelt and shoulder harness constraints. However, the anthropometric data base begins with a 50th

percentile person,and different depictions require statistical regression from the data base (i.e., 5th or 95th percentile). Furthermore, the batch input requirement limits the operator by not allowing interactive data input. An offshoot of the Boeman model is the Crew Assessment of Reach (CAR) model (10:24). This model capitalizes on interactive data input and entire population anthropometric data regression, but it is extremely limited by the lack of graphical display. Again, this model is useful only for design of a cockpit environment.

Another industry entry is Cyberman that was developed by the Chrysler Corporation. It is a 15-link figure portrayed in 3d, vector graphics and allows depicting a human from any percentile (10:19). Although it offers reach, clearance, and visual interference analyses, lack of human constraint programming restricts the simulation of realistic movement (the human model can conceivably reach the top of its head from the back). Next, Rockwell International developed Buford (10:22). In using Buford, the operator defines a 50th percentile human model and then circumscribes the environment around the model through interactive, 3d, vector graphics. While Buford does allow reach and clearance assessment, the model requires the operator to orchestrate the limb movements and visually evaluate reach success or failure and clearances. Moreover, the model does not provide visual assessments from Buford's

viewpoint. All of the models developed by industry have two things in common. First, they only consider the human form for ability to reach or see an item or control mechanism in a cockpit environment. Secondly, they do not simulate real-time human motion. However, real-time simulation of human motion has been emphasized in academic research, along with further applications for ergonomic design.

Academic Models

Academic research has developed four notable human models. First, Calvert, et al. (5:46) developed a 23-joint, 22 segment model that is input into the computer in batch mode or "from the analog outputs of an electrogoniometer." The human model output is a stick man with simulated kinematic motion rather than dynamic motion. Another limitation of the model concerns realistic motion simulation. As it now stands, the operator is required to monitor the output for unnatural movement patterns because a simulation feedback loop is not included in the program to correct abnormalities. Calvert, et al. (5:48) propose three applications for this model:

> . . . as a tool to assist in the notation of dance and as a tool for visualization of dance notation.
>
> . . . the clinical assessment of movement abnormalities.
>
> . . . using the macrolanguage developed from animation of human figures to control a robot manipulator arm.

Next, Badler, et al. (2:14) developed "BUBBLEMAN". The model uses 20 links and 19 joints to portray the human form in either vector graphics (two dimensional circles) or 3d, raster graphics. In the two dimensional model, the representation includes 600 overlapping spheres that are depicted as circles. The 3d model allows full body enfleshment and depth through color graphics and shading. Although initial input is restricted to the batch mode, the system allows interactive manipulation of the model. Badler, et al. apply the simulation for two purposes (2:1401):

> One to combine the human model with existing cockpit design and crash simulations systems, the other to transform a symbolic human movement notation system into a graphic animation.

The model provides reach, collision, and visual perspective assessments. Also, they have programmed the model for clothing simulation. Furthermore, the model incorporates a motion feedback loop so "it will always position the body in a legal achievable position [14:526]."

The third model, "Fourth Man", is an evolutionary paradigm developed under the direction of William A. Fetter (11). Its forerunner, "First Man", was developed for cockpit configuration analysis of the Boeing 747 and paralleled "Boeman". Later, it was expanded from a sitting, seven-segmented model, based on a 50th percentile male, to "a more fully articulated 19-segment figure [11:10]" called "Second Man". This model allowed animating motions in the

simulation. Fetter continued his research and expanded the model to the third generation under the auspices of Southern Illinois University ("Third Man and Woman"). This paradigm employed 100 points for anthropometric simulation of 50th percentile people. Finally, "Fourth Man" evolved and incorporates raster graphics into the human model. However, the primary emphasis of "Fourth Man" encompasses realistic simulation of the human appearance and realistic movement.

Lastly, E. C. Kingsley, et al. developed the "System for Aiding Man-Machine Interaction Evaluation" (SAMMIE) at the University of Nottingham, England. SAMMIE includes both a 3d, CAD system and an "anthropometric and bio-mechanical man model [12:163]" in the software package. It employs interactive, 3d, vector graphics. The system embodies the human model through 21 links and 17 joints with allowances for somatotypes (thin, medium, or fat) and a generic, anthropometric data base for male and female depiction. Assessment diagnostics include reach, fit, and visual perspectives from the man-model or from the man-model via a mirror. Although SAMMIE provides an excellent tool for ergonomically designing work places and equipment (7:28), it does not consider lifting, pulling, pushing, or strength capacities for tool or equipment manipulation. Furthermore, Compeda Ltd., Stevenage, England, now owns the system's copyright which constrains adapting the model to Air Force requirements.

Military Models

The last category of computerized human models, i.e., military applications, traditionally lags both commercial and academic applications. Also, the military models are usually developed in conjunction with industry or an academic institution. Four examples of this co-production are: the STICKMAN Program, the Cockpit Geometry Evaluation Program, the COM-GEOM Technique, and the COMBIMAN Program.

In 1970, the Federal Systems Division of International Business Machines Corporation (IBM) developed the STICKMAN Program with the Air Force Aerospace Medical Research Laboratory (AMRL). Its specific purpose was "studying human body segment mass and centers of mass [20:1]." The program employed batch card input with alterations by either light pen or keyboard commands. Output consisted of a two dimensional, stick figure with 11 body reference points and 23 mass or center of mass computations displayed on a cathode ray tube or printed in hard copy. Consequently, the model simulated neither task, equipment, environment, nor motion.

Secondly, the Cockpit Geometry Evaluation Program (17:7) utilizes the 23-joint figure of "Boeman". In fact, the model was developed by the Boeing Corporation and the Office of Naval Research for the Joint Army-Navy Aircraft Instrumentation Project. Consequently, the paradigm has all the characteristics of the aforementioned "Boeman".

However, the study recommended including strength capacities for the crew members in future expansions of the model.

Next, the COM-GEOM (Combinatorial Geometry) technique, developed by the Army (13:1), portrays the human form with 23 geometric solids in 3d. Although the primary body positions are sitting and standing, the geometric solids can be rearranged to simulate other body positions as required for analysis. The model bases its anthropometric data on 50-60th percentile personnel. Further, model definition includes depicting the human form with or without a helmet. Body weight and density calculations are available within the software for target and wound assessment; the operator can make reach and fit assessments for a weapon system based on his judgment.

Finally, AMRL and the University of Dayton Research Institute jointly developed the Computerized Biomechanical Man-Model (COMBIMAN) "to serve as an interactive-computer-graphics-assisted engineering tool to represent geometric and physical properties of a person at a crew station [3:17]." A 35-link skeletal system with circumscribed ellipses defines the human body. The anthropometric data base for the simulation allows depictions of any percentile USAF personnel. Also, the model permits the operator to assess reach envelopes with or without seatbelt and/or shoulder harness constraints. Visual field assessments require operator judgment from hard copy printouts of line-

of-sight azimuth and elevation angles. Initializing the system requires batch input, but the interactive graphics allow operator construction and manipulation of simulation parameters.

Summary

With the exception of SAMMIE, the existing models are not sufficiently generic to permit ergonomic design considerations for a maintenance technician. Both the industrial and military models portray the human form in a sitting position and concentrate on work space design for a person in a cockpit environment. The academic models focus on the simulation of the human body in real-time motion. In the case of SAMMIE or BUBBLEMAN, the primary task simulates the human in a cockpit environment. With the current emphasis on maintainability and supportability in weapon systems, it is imperative that a computer graphics model of the maintenance technician be developed for use in evaluating proposed equipment designs.

CHAPTER 3

METHODOLOGY

The approach used to obtain data to answering the research questions was to interview a sample of experienced maintenance officers and human factors specialists and to collect their opinions regarding a series of structured questions. This chapter presents the operational definitions used in developing the interview schedule, the criteria employed for selecting the sample and each subgroup, the data analysis methods for each question in the interview schedule, and the assumptions applied to the research.

Operational Definitions

This section addresses the kinds of maintenance tasks to be performed, the characteristics of the human model which could perform these tasks, and the personal information to be obtained on each person interviewed.

Maintenance Tasks

These are work activities performed by the technician in order to keep the aircraft flying. Ostrofsky (15:234) defines maintenance "as the tasks or activities required to maintain a predetermined level of system performance." Ostrofsky (15:234-235) defines seven general

maintenance task categories, while Blanchard and Lowery define 11 (4:310). These categories encompass and overlap the 19 maintenance tasks outlined in MIL-STD-1388-2 (19:46). However, this research is limited to line maintenance activities. Therefore, any tasks performed by depot level or shop technicians are not considered. Consequently, Ostrofsky's seven general activities provide the descriptive breakdowns (15:234-235) for this research. His seven categories are:

> CALIBRATE (OR ADJUST). The tasks required to regulate or bring the performance of a given level of the system to within acceptable output tolerance.
>
> INSPECT. Observation or test to determine the condition or status of the system (or lower element of the system).
>
> REMOVE. The tasks required to remove a desired portion of the system.
>
> REPAIR. The tasks required to restore a given level of the system to operating condition.
>
> REPLACE. The tasks required to replace the desired portion of the system given that a removal has occurred.
>
> SERVICE. The replenishment of consumables needed to keep a given level of the system in operating condition.
>
> TROUBLESHOOT. The tasks which isolate a fault or failure to the desired level in the system.

Human Model

There are three subcategories considered in defining the human model: body positions required to accomplish the maintenance tasks, human factors assessment diagnostics,

and clothing. First, the body positions required to perform the maintenance tasks are defined as follows:

SUPINE - person is lying flat on back with face up.

PRONE - person is lying flat on stomach with face down.

KNEELING - person is resting on both knees in upright position.

SITTING - person is resting on buttocks in upright position.

STANDING - person is erect at full stature.

CRAWLING - person is on hands and knees.

BENDING - person stands on feet and bends forward at the waist.

SQUATTING - person rests on heels with knees bent.

CLIMBING - person is erect and in the act of ascending or descending a ladder.

The next subcategory for the human model involves human factors diagnostics. These diagnostics are aids to the designer in assessing whether the technician can work in the space provided. Reynolds (16:5) referred to them as "Compliance Evaluations". Further definitions follow:

FIT - The person's ability to work comfortably within the space provided with his arms or entire body and with the required tools.

REACH - The person's ability to achieve the required position using normal arm flexion.

VISUAL FIELD OF THE TECHNICIAN - The person's ability to see the equipment to be maintained.

LIFTING CAPACITY - The person's ability to lift the equipment without straining himself.

PULLING - The person's ability to pull the equipment without straining himself.

PUSHING - The person's ability to push the equipment without straining himself.

Finally, clothing is defined as those uniforms and/or protective gear that the maintenance technician must wear in order to perform the tasks satisfactorily. The least restrictive uniforms are fatigues and flight suits, whereas the most constraining uniforms are the protective gear provided by cold weather operations and chemical/biological warfare environments.

Personal Information

This section of the interview schedule provides personal reference information. It supplies the following information about each interviewee: career field; experience in the field in months; and name and office title as a reference for the anecdotal information obtained in Question 9.

Sample Criteria

This research effort employed a structured, purposive interview of 30 people involved in maintainability and supportability decisions within the acquisition process. The total population entailed all military and government civilian personnel, and contractor personnel that impact maintainability and supportability decisions. Due to cost and time constraints, the target population was limited to those military and civilian personnel participating in

maintainability and supportability decisions that are located at Wright-Patterson AFB, Ohio. For the purpose of judgmental sampling and time constraints, the sampling plan encompassed two categories: Human Factors Engineers, and Maintenance Officers. Fifteen persons were interviewed in each subgroup and were selected for availability and convenience. Each category offered unique experience insights into the requirements of the model. First, the human factors engineers supplied the necessary information for the model's anthropometric and bio-mechanical characteristics. Then, the maintenance officers provided the viewpoint from the weapon system's and maintenance technician's operational phase.

Data Analysis Methods

The relatively small sample size and the ordinal nature of the data made hand tabulation easier than computerizing the process. The following presentation outlines the data analysis employed for each question in the interview schedule (Appendix A).

QUESTION 1: This question requires the respondent to rank the alternatives. For the express purpose of prioritizing the tasks for simulation, a two step data analysis process was used. First, the statistical modes of the ranks supplied the initial prioritization. Then, in case of any ties, the statistical mean was calculated and the task with the lowest mean received the higher ranking. This ranking process was applied to both categories and the entire sample for subjective evaluation, as well as prioritization.

QUESTION 2: This question required supplying additional maintenance tasks for simulation. The author required a subjectively sufficient number of respondents to mention the task if it was to be included.

QUESTION 3: This question required the respondents to associate body position(s) with each maintenance task. First, the responses were tallied for each body position by task. This formed a seven by nine matrix with the tasks as the rows and body positions as the columns. Next, the responses were ranked by body position for each task, i.e., the body position with the most responses received the highest rank (1). Finally, the body positions were prioritized using the statistical mode initially and the lower statistical mean of the ranks for breaking any ties. This process was applied to both subgroups for subjective difference analysis and to the entire sample for prioritization.

QUESTION 4: This question required providing additional body positions for simulation. Like Question 2, an additional body position for simulation required mentioning by a subjectively sufficient number of respondents.

QUESTION 5: This question required the respondent to rank the human factors assessment diagnostics. Data analysis for this question entailed employing the two step priority method discussed in Question 1.

QUESTION 6: This question required supplying additional human factors assessment diagnostics. Like Questions 2 and 4, inclusion of an additional human factors assessment diagnostic required suggestion by a subjectively sufficient number of the sample.

QUESTION 7: This question expected the respondent to rate the importance of operational clothing requirements for the maintenance technician using a scale from 0 (not applicable) to 6 (critical). The final determination of the importance of clothing considerations for simulation is based on a simple arithmetic average of the responses and the author's judgment.

QUESTION 8: If the clothing considerations of Question 7 are rated 4 or higher, the greater number of responses for either cold weather gear or chemical warfare gear determined the more important of the two for simulation.

QUESTION 9: This question asked the interviewee to relate personal observations about lack of maintainability in existing weapon system designs. The anecdotal information required transcription and tabulation for type and specific instances of lack of maintainability and supportability in system designs.

QUESTION 10: This question provides the interviewer with a check on the number of people interviewed in each subcategory.

QUESTION 11: This question required the respondent to provide his experience in his particular career field expressed in months. A statistical mean and standard deviation for each subgroup is calculated as an indication of the level of experience within each subgroup.

QUESTION 12: The question did not lend itself to data analysis.

QUESTION 13: The question did not lend itself to data analysis.

Assumptions

Since this research was an exploratory effort to determine the functional specifications of the computerized model of a maintenance technician, I made no assumptions about the distributions of the answers by the target population or each subpopulation. However, I assumed that every person interviewed was sufficiently experienced in his field to provide adequate responses for prioritizing the specifications of the model.

CHAPTER 4

RESULTS

This chapter presents the findings from the data collected using the interview schedule in Appendix A. Also, it associates the research questions with the applicable interview questions. Since there are no applicable research questions for the Personal Information section of the interview schedule, these questions are analyzed last.

Research Question 1

What general maintenance tasks should the model simulate for maintainability and supportability considerations?

Interview Question 1

Rank the following maintenance activities according to their importance for maintainability and supportability considerations.

According to the results (Table 1), both the human factors engineers and the maintenance officers ranked troubleshooting as the primary task for simulation. Although the subgroups disagreed on the second task for inclusion, the total sample mode and mean rank for inspection placed it ahead of adjustment and calibration in priority. Like-

TABLE 1

MAINTENANCE TASK PRIORITIZATION

Priority	Maintenance Task	Subgroup: Maintenance Officers Mode	Subgroup: Maintenance Officers Mean	Subgroup: Human Factors Engineers Mode	Subgroup: Human Factors Engineers Mean	Total Sample Mode	Total Sample Mean
1	Troubleshoot	1	2.733	1	1.867	1	2.3
2	Inspect	1.5	3.1	4	4.1	2	3.6
3	Adjust/ Calibrate	7	4.567	2	3.067	2	3.817
4	Remove	3/6.5	4.3	4	4.1	3	4.2
5	Replace	3/6.5	4.8	2/4.5 5.5/7	4.567	3	4.683
6	Repair	3/5	4.5	6	5.2	5/6	4.85
7	Service/ Lubricate	1.5/7	4.0	7	5.1	7	4.55

wise, remove and replace modal rankings differed between subgroups, but the statistical means were relatively close. Since the sample modes were identical (mode = 3), the priority decision rule for ties based on sample means was invoked and remove was prioritized before replace. Even though the maintenance officers ranked repair higher than the human factors engineers, the sample mode and mean placed the task in the sixth position for simulation. Service and lubrication assumed the last priority based on the modal rankings of both subgroups and the sample mode.

Interview Question 2

Are there any other maintenance activities not covered that you consider important for simulation?

Only four respondents answered this question with additional activities for simulation. Two indicated the need for simulating launch and recovery operations. However, the activities required for completing the launch and recovery operations are covered by the seven generic activities. Another interviewee supplied weapons loading and unloading as his answer. Weapons loading is an installation much like the replace activity defined, and unloading is a removal task. Lastly, one person intimated the need to simulate tool manipulation for safety considerations. Although this suggestion is important, the implication is too microscopic for the purposes of this research.

Research Question 2

What body positions are relevant to these maintenance tasks?

Interview Question 3

Which body position(s) do you associate with each applicable task?

Table 2 illustrates the data analysis results. As depicted by the subgroup modes and means, and the sample mode and mean, standing is the preferred position for all tasks. However, the subgroups disagree on whether sitting or kneeling should be simulated next. Nevertheless, the priority setting rule placed sitting ahead of kneeling because of the sample mode for the position for each task. Further disagreement occurred between kneeling and squatting. While the maintenance officers clearly preferred kneeling over squatting, the human factors engineers indicated squatting as a definite third and kneeling as either a second or fourth priority. Regardless of the disparity, the sample mode and mean placed kneeling third and squatting fourth. The fifth body position was a unanimous decision (bending at the waist).

The last four body positions exhibited disagreement between the subgroups. Climbing had a tri-modal rank by the maintenance officers, but the mean rank agreed with the mode and mean ranks of the human factors engineers. Also,

TABLE 2

BODY POSITION PRIORITIZATION

Priority	Body Position	Subgroup: Maintenance Officers Mode	Maintenance Officers Mean	Human Factors Engineers Mode	Human Factors Engineers Mean	Total Sample Mode	Total Sample Mean
1	Standing	1	1.286	1	1.0	1	1.143
2	Sitting	2.5	3.143	2	3.0	2	3.071
3	Kneeling	3	2.857	2/4	2.929	3/4	2.893
4	Squatting	4	3.143	3	3.429	4	3.286
5	Bending at Waist	5	4.857	5	4.786	5	4.821
6	Climbing	5/6 6.5	6.0	6	6.214	6	6.107
7	Prone	8/8.5	8.07	7	7.286	7/8	7.679
8	Supine	7.5/8 8.5	7.857	8	8.286	8	8.071
9	Crawling	6.5/8 9	7.786	9	8.071	9	7.923

this concurred with the mode and mean for the total sample. The prone position received the rank of seventh based on the sample mode and mean. Supine was placed eighth and climbing ninth based on the priority rule for the sample. As indicated, the maintenance officers had multimodal preferences for these three body positions. The human factors engineers, however, were more pragmatic. They indicated the prone position as seventh, with supine and crawling in eighth and ninth, respectively. The general reasoning for ranking these positions last was the limited time a person could remain in the position and still work efficiently.

Interview Question 4

Are there any other body positions relevant to the model?

This open-ended question produced six additional body positions from 11 respondents. The position, standing on one's head, was mentioned by three maintenance officers from fighter backgrounds. Although this position represents an "as is" condition, these three people felt the confined maintenance environment of the cockpit warranted simulation of this body position. Next, two interviewees cited a spread-legged stand as a position required for service and lubrication, and remove and replace tasks. The reasoning for this body position was the requirement for tall personnel to work under the wings and inside the access panels

of fighter aircraft. Another position specified by two maintenance officers was a standing position with a backwards bend at the waist in order to work on components located in a wheelwell. Also, hanging in a harness was suggested as a possible position for simulation by two other respondents. Finally, one human factors engineer mentioned walking and another maintenance officer suggested lying on one's side as other positions to simulate. Nevertheless, none of these body positions were deemed sufficiently specified for inclusion in the model at this time.

Research Question 3

What human factors assessment diagnostics are required in the model in order to optimize the human factors/ maintainability interface with the weapon system design?

Interview Question 5

Rank the following human factors assessment diagnostics as to their usefulness in the model.

As indicated in Table 3, both the maintenance officers and the human factors engineers cited the ability of the body or limb to fit into a given area as the primary diagnostic for simulation. Even though the subgroups disagreed on the second and third priority, the total sample mode and mean placed reach second, followed by simulating the visual field of the maintenance technician. Lifting

TABLE 3

HUMAN FACTORS ASSESSMENT DIAGNOSTICS PRIORITIZATION

Priority	Human Factor Assessment Diagnostic	Maintenance Officers Mode	Maintenance Officers Mean	Human Factors Engineers Mode	Human Factors Engineers Mean	Total Sample Mode	Total Sample Mean
1	Fit	1	1.6	1/2	1.8	1	1.7
2	Reach	2	2.2	3	2.533	2	2.367
3	Visual Field of Technician	3	3.067	1/3	2.433	3	2.75
4	Lifting	4/5	4.0	4	4.2	4	4.1
5	Pulling	5.5	4.6	5	4.867	5.5	4.733
6	Pushing	5.5	5.33	5/5.5 6	5.167	5.5	5.25

capacity was ranked fourth, with pushing and pulling tied for fifth in the sample modes. Since the sample mean for pulling is less than the sample mean for pushing, pulling is ranked fifth and pushing ranked sixth.

Interview Question 6

Are there any other assessment diagnostics relevant to the model?

This question provided the first answer deemed sufficiently mentioned for inclusion in the model. Eight people thought strength/torque assessments for tool manipulation in awkward positions required simulation. This response presented an assessment diagnostic overlooked in formulating the interview schedule. Other specified assessment diagnostics included support of the body in a confined area (1 person), environmental assessments for heat and cold stress (1 person), coordination between two or more technicians working on the same aircraft (3 persons), using special equipment for special tasks (1 person), probability of error (1 person), and ability to hear in a jet engine environment (1 person).

Research Question 4

What operational clothing requirements are relevant to the model simulation?

Interview Question 7

How important are clothing considerations to the model?

Based on the scale from 0 to 6, both subgroups indicated clothing as very important. For the maintenance officers, the mean rating was 4.9 with a standard deviation of .604 and a mode equal to 5. The human factors engineers rated clothing slightly higher (mean = 5.33; standard deviation = .919; and mode = 6). The sample statistics provided similar results (mean = 5.12; standard deviation = .795; and mode = 5). Only one respondent supplied a rating less than 4.

Interview Question 8

If Question 7 is rated 4 or more, which clothing type is more important?

Of the 30 interviewees, 22 considered chemical warfare gear more important than cold weather gear due to the more restrictive nature of the protective equipment. Five perceived cold weather gear as more important, and only two felt there was no difference between the protective clothing.

Personal Information

Interview Question 9

Do you have any anecdotal information about lack of maintainability and designs?

The general response highlighted lack of accessibility and visual ability for working on components on the aircraft. This was especially true for fighter aircraft. As a prime example, the F-4 UHF radio required removal of the aft ejection seat in order to replace the low reliability component. Also, this weapon system used over 50 different fasteners for external access panels. Also, if a component requires safety wiring after replacement, the lack of visual interface for the maintenance person resulted in less than optimal safety wiring or circumventing remove and replace actions by replacing the interior mechanism of the black box. This applied to large aircraft as well as fighters. However, the respondents with experience in maintaining the F-15, F-16, and A-7 indicated these aircraft provided excellent examples for improved maintainability for the maintenance technician.

Interview Question 10

What is your present career field?

The purposive sample design provided 15 maintenance officers and 15 human factors engineers.

Interview Question 11

How many months experience do you have in this career field?

Of the two subgroups, the human factors engineers had the most experience in their respective career field. The mean experience for this subgroup equalled 167.07 months with a standard deviation of 104.035 months over a range of 6 to 348 months. Although the maintenance officers' experience levels were lower, the statistics indicated sufficient knowledge to benefit the study (mean experience level = 56 months; standard deviation = 33.6 months; and range from 24 to 120 months).

Interview Questions 12 and 13

These questions did not warrant analysis due to the subjective nature of the responses. However, none of the respondents refused permission to use their names or office titles as referenced for the study.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The following pages summarize the results presented in Chapter 4 and outline recommendations for further exploration.

Conclusions

Research Question 1

What general maintenance tasks should the model simulate for maintainability and supportability considerations?

All respondents found the seven generic maintenance tasks sufficiently general for simulation of all tasks required of a line maintenance technician. Furthermore, the tasks were general enough for application to cargo, tanker, and bomber aircraft, as well as fighters. According to the data analysis, the respondents prioritized the tasks as follows:

Priority	Task
1	Troubleshooting
2	Inspection
3	Adjust/Calibrate
4	Remove
5	Replace
6	Repair
7	Service/Lubricate

Since these tasks were fairly comprehensive, no additional tasks were included for simulation.

Research Question 2

What body positions are relevant to the performance of these maintenance tasks?

The interview results indicated the preferred body positions for all tasks were standing and sitting. If any other body positions required simulation, both the maintenance officers and the human factors engineers favored kneeling, squatting, and bending at the waist over climbing, prone (lying face down), supine (lying face up), and crawling. Consequently, their responses prioritized the positions for simulation as follows:

Priority	Body Position
1	Standing
2	Sitting
3	Kneeling
4	Squatting
5	Bending at the Waist
6	Climbing
7	Prone (lying face down)
8	Supine (lying face up)
9	Crawling

Again, these body positions were considered generic enough that no other body positions are required for simulation.

Research Question 3

What human factors assessment diagnostics are required in the model in order to optimize the human factors/

maintainability interface with weapon system design?

Of the six evaluation diagnostics mentioned in the interview, the sample selected fit, reach, and visual field of the technician as the most relevant for computerization. Next, lift received priority over pulling and pushing. Moreover, an additional human factors assessment diagnostic received significant mentioning by the sample for inclusion in the model. This additional diagnostic was strength/ torque applications for tool manipulation or the ability of the technician to apply sufficient force to complete the operation given that the technician can fit into the access area and reach the specified component. Based on the responses of the interviewees, the human factor diagnostics are prioritized as follows:

Priority	Diagnostic
1	Fit
2	Reach
3	Visual Field of the Technician
4	Lift
5	Pull
6	Push
Added	Strength/Torque

Research Question 4

What operational clothing requirements are relevant to the model simulation?

According to both subgroups and the entire sample, operational clothing requirements, which include cold weather and chemical warfare gear, are very important and,

therefore, very relevant. Furthermore, simulating a technician outfitted in chemical warfare gear rated higher in importance than a technician dressed in cold weather gear. Consequently, if a weapon system is designed for minimum dimensions for a maintenance technician, the model must simulate a 95th percentile person in full ground crew chemical warfare ensemble.

Recommendations

1. In order for the paradigm to realistically simulate a technician clothed in chemical warfare gear, existing anthropometric data bases require updated dimensions for static measurements of personnel in the ground ensemble rather than using a percentage factor for the increased dimensions.

2. Design engineers and maintainability engineers should be interviewed for their experience inputs concerning maintainability and supportability considerations in weapon system design.

3. Completing the interface with existing CAD systems necessitates surveying contractors for CAD systems employed and available computer memory for the model.

APPENDIX

APPENDIX

INTERVIEW SCHEDULE

INTERVIEW SCHEDULE

The purpose of this interview is to determine the functional requirements for a computer-based, bio-mechanical maintenance technician model for interface with existing CAD systems throughout the aerospace industry. The interview covers three distinct areas: the generic maintenance tasks required, the human model, and assessment diagnostics for effective human factors/design tradeoffs.

MAINTENANCE TASKS

1. Rank the following general maintenance activities according to their importance for maintainability and supportability simulation?

    adjust (calibrate)

    inspection

    removal

    repair

    replace

    servicing/lubrication

    troubleshooting

2. Are there any other maintenance activities not covered that you consider important for simulation?

HUMAN MODEL

3. Which body position(s) do you associate with each applicable task?

    adjustment/calibration

        supine

        prone

        kneeling

        sitting

        standing

crawling

bending

squatting

climbing

inspection

supine

prone

kneeling

sitting

crawling

bending

squatting

climbing

removal

supine

prone

kneeling

sitting

standing

crawling

bending

squatting

climbing

repair

supine

prone

- kneeling
- sitting
- standing
- crawling
- bending
- squatting
- climbing

replace

- supine
- prone
- kneeling
- sitting
- standing
- crawling
- bending
- squatting
- climbing

servicing/lubrication

- supine
- prone
- kneeling
- sitting
- standing
- crawling
- bending
- squatting
- climbing

troubleshooting

supine

prone

kneeling

sitting

standing

crawling

bending

squatting

climbing

4. Are there any other body positions relevant to the model?

5. Rank the following human factors assessment diagnostics as to their usefulness in the model.

Fit

Reach

Visual field of the technician

Lifting capacity

Pulling

Pushing

6. Are there any other assessment diagnostics relevant to the model?

7. How important are clothing considerations to the model?

n/a		undecided		critical		
0	1	2	3	4	5	6

8. If more than undecided,

Which is more important?

Cold Weather Gear

Chemical Warfare Gear

PERSONAL INFORMATION

9. Do you have any anecdotal information about lack of maintainability in designs?

10. What is your present career field?

1 - human factors engineer

2 - maintenance officer

11. How many months experience do you have in this career field?

12. Do you have any reservations about using your name and office title as a reference for this study?

Yes

No

13. If no,

Name

Office Title

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